How much could refuges help us recover from a global catastrophe?

Nick Beckstead, Future of Humanity Institute, University of Oxford

Forthcoming in *Futures*

Abstract

Some global catastrophes (such as nuclear wars, pandemics, or an asteroid collision) might destroy civilization. Some propose building well-stocked shelters constantly staffed with people trained to rebuild civilization in such cases. These "refuges" would have an unimpressive expected cost per life saved, but could conceivably have an impressive expected cost per future generation allowed to exist. From some ethical perspectives that highly value future generations, building refuges may therefore seem like a promising idea. However, several factors significantly dilute the potential impact of refuges, even if the proposed catastrophes occur. Government/private disaster shelters, people working on submarines, and isolated peoples who prefer to be left alone serve these purposes to some extent already. Many proposed catastrophes do too much/too little damage for refuges to help, affect the environment in ways that make refuges largely irrelevant, or otherwise give relatively limited advantages to the people in refuges. In global food crises or social collapse scenarios, refuges would add little to aggregate stocks of population, resources, food, and relevant skills; but they may add something unique in terms of isolation and coordination. These potential benefits of refuges seem the most promising, and may be worthy of further analysis.

Keywords: global catastrophic risk, existential risk, refuges, disaster shelters, bunkers, social collapse

Highlights

- Global catastrophes like nuclear wars or pandemics might destroy civilization.

- Some propose building “refuges” to aid survival and recovery in such cases.
- Government/private shelters, subs, and isolated peoples serve similar goals.
- Refuges could only be crucial in a small portion of proposed catastrophe scenarios.

Section 1: Introduction

As discussed elsewhere in this issue, a number of different global catastrophes could conceivably result in the collapse of civilization and/or the extinction of humanity in the coming century. Several authors (e.g. Matheny, 2007; Hanson, 2008; Jebari, 2014) have recommended investing in well-equipped bunkers, disaster shelters, or “refuges” specifically designed to withstand a would-be extinction event would increase the chances that humanity would recover from a global catastrophe. Refuge construction can be seen as an example of increasing civilization’s overall resilience to global catastrophes, as advocated by Maher and Baum (2013).

Even though projects of this kind would probably have a high cost per life saved, they may have an exceptionally low expected “cost per future generation allowed to exist.” From some philosophical perspectives that highly value future generations (such as Parfit,1984; Bostrom 2003, 2013; Author 2013), this makes the construction of such refuges a potentially promising idea.

Section 2 offers a brief review of three papers proposing to build/improve refuges in order to increase the probability of recovery from a catastrophe. Section 3 reviews existing networks of government/private disaster shelters, people working on submarines, and isolated peoples who prefer to be left alone. These groups and infrastructure already serve the intended function of refuges to some extent. Section 4 reviews proposed global catastrophes, considering for which of them refuges could or could not be useful. Many proposed catastrophes do too much/too little damage for refuges to help, affect the environment in ways that make refuges largely irrelevant, or otherwise give relatively limited advantages to the people in refuges. In global food crises or social collapse scenarios, refuges would add little to aggregate stocks of population, resources, food, and relevant skills. However, they may add

something unique in terms of isolation and coordination. These potential benefits of refuges seems the most likely, and may be worthy of further analysis.

Section 2: Literature advocating for the creation of refuges

In "Catastrophe, Social Collapse, and Human Extinction," Hanson (2008, p. 373) writes:

> "…there may be types of disasters where variations in resistance abilities can be important. If so, there might be a substantial chance of finding a post-disaster population that is just above, or just below, a threshold for preserving humanity. In this case it is reasonable to wonder what we might do now to change the odds. The most obvious possibility would be to create refuges with sufficient resources to help preserve a small group of people through a very large disruption, the resulting social collapse, and a transition period to a post-disaster society."

In "Reducing the Risk of Human Extinction," Matheny (2007, p. 1337) writes:

> "Perhaps more cost effective than building refuges in space would be building them on Earth. Elaborate bunkers exist for government leaders to occupy during a nuclear war (McCamley, 2007). And remote facilities are planned to protect crop seeds from "nuclear war, asteroid strikes, and climate change" (Hopkin, 2007). But I know of no self-sufficient, remote, permanently occupied refuge meant to protect humanity from a range of possible extinction events. Hanson (2007) argues that a refuge permanently housing as few as 100 people would significantly improve the chances of human survival during a range of global catastrophes. The Americas and Polynesia were originally populated by fewer than 100 founders (Hey, 2005; Murray-McIntosh et al., 1998). Although it would take thousands of years for 100 people to repopulate Earth, this would be a small setback compared to extinction."

And in "Existential Risks: Exploring a Robust Risk Reduction Strategy," Jebari (2014, p. 12) writes:

> "In engineering safety, a number of heuristics and strategies are device[s] to prevent a catastrophic failure in a large number of possible scenarios. These strategies could be employed in thinking about how to reduce the risk of a black swan extinction event. Safety barriers are an instance of such a strategy. These could be actual physical barriers in some systems, or subsystems that prevent catastrophic failure by compartmentalization and physical separation. This article has discussed an example implementation of this strategy: isolated, continuously manned and self-sufficient underground refuges that could protect a large enough number of people to ensure the continued existence of mankind."

We'll use these three papers as representative of the sort of proposal discussed in this paper.

Section 3: Where would people be especially likely to survive a global catastrophe?

Government bunkers for private citizens, government bunkers for continuity of government, shelters purchased by private citizens, people working on submarines, and people living in remote locations would be especially likely to survive a global catastrophe. Examining these unintentional refuges will help us assess to what extent creating refuges of the type proposed above—or other types of refuges—would increase the chances of recovery from a global catastrophe.

A brief note on terminology: "Bunker" and "shelter" seem to be used largely interchangeably, but "bunker" is more often used to describe large shelters built by the government. Government buildings, including bunkers, designed to withstand severe stress are sometimes called "hardened facilities." Private shelter providers tend to use "shelter" to describe their products, and this document follows that usage when describing their products. In this paper, "refuge" is used roughly to mean "place specifically designed to be especially likely to survive a global catastrophe and aid in the subsequent recovery."

Government bunkers for private citizens

As of 1986, the reference Nuclear War Survival Skills judged that, "Switzerland has the best civil defense system, one that already includes blast shelters for over 85 percent of all its citizens." They have 300,000 communal bunkers, which another source claims is enough for the entire Swiss population of 7.6 million, with a million spaces to spare. These bunkers are stocked with 4.5 months of food and basic fuel. In addition, a 1978 law requires all residential buildings to have a fallout shelter capable of withstanding a 12-megaton explosion at a distance of 700 meters or pay a fee. However, people building single-family homes typically pay the fee instead of building the shelters (Ball 2011).

Continuity of government bunkers

"Continuity of government" bunkers exist in at least Canada, Denmark, France, Germany, Norway, Russia, Sweden, the United Kingdom, the United Sates. This section will briefly discuss what kind of bunkers exist in the United States.

During the Cold War, the US government spent billions of dollars to build a network of bunkers designed to preserve continuity of government in the event of a nuclear strike against the US, the full extent of which is still unknown (Hodge and Weinberger, 2008, p. 134). Much information about continuity of government bunkers is classified—one report suggests that even members of Congress can't get the full details of the plan (Kosseff, 2007)—and this makes it difficult to know much about their current capabilities. Some known continuity of government bunkers include Cheyenne Mountain, Mount Weather, Raven Rock (also known as "Site R," see Hodge and Weinberger (2008, p. 133)), and U.S. Strategic Command. Additional bunkers are rumored to exist underneath the White House and at the Camp David Presidential retreat in Maryland (Hodge and Weinberger 2008, p. 132). Project Greek Island was a top secret bunker, built underneath the Greenbrier resort in Western Virginia, that would be used to house members of Congress in the event of a nuclear strike. It was exposed by a journalist in 1993 and is

no longer in operation. This suggests the possibility of other bunkers that might be off of the public record.

One concern about the effectiveness of these bunkers is that if people were notified that nuclear missiles were en route to the US, there may not be enough time for people to get inside of the bunkers. Another possible concern is that they would not have an appropriate gender mix to repopulate civilization. Mount Weather was initially built as an all-male facility.

Historically, continuity of government bunkers were built primarily with nuclear war in mind, but people managing these bunkers have begun to consider threats like pandemic influenza (Hodge and Weinberger 2008, p. 137-138, 141, 150).

Shelters purchased by private citizens

As of 2010, Radius Engineering—a private shelter provider—had built 1100 shelters, about a third of which were in the Washington D.C. Area (Patrol Log, 2010). Radius Engineering estimates that 10,000 people on three continents have access to their shelters. Radius Engineering describes the capability of their shelters as follows:

> "Radius underground WMD shelters are totally self-contained structural C3 Composite high pressure structures designed to protect 8-200 adults for 6 months to 5 years. Multiple shelters can be connected into underground communities. The shelters are specifically designed and developed to protect people during and after disasters such as tornadoes, hurricanes, earthquakes, firestorms, power failures, nuclear & chemical accidents, nuclear, biological, & chemical terrorism, and full-scale protracted nuclear, chemical and biological war and severe HEMP attacks….Radius shelters are used throughout the world to protect people for Business Contingency Plans (BCP's) in military, medical, corporate markets and Family Contingency Plans (FCP) for families."

Another US-based private shelter provider is Vivos. As of November 2012, Vivos had received about 25,000 applications for 6,000 planned spaces, and three facilities—each designed to hold 1,000 people—were being constructed. One shelter, located in a remote part of Indiana, has been completed. Vivos' shelters will include one year of food reserves and a "Cryovault" carrying sperm and eggs in hopes of helping to repopulate the earth in the event of a global catastrophe.

Submarines

People serving on submarines might be in a good position to survive many global catastrophes. According to the US Navy, US nuclear submarine crews typically have over 100 people, and can stay underwater for more than 90 days. The US has the largest submarine force in the world, with 59 nuclear submarines in 2014.

There is a question of whether submarines have an appropriate gender mix to repopulate civilization. According to the Navy Times, the first women are scheduled to begin working on US submarines in 2015, though some other countries started permitting women on their submarines in the 1980s.

Isolated peoples that prefer to be left alone

Survival International—an advocacy organization—estimated that there are over 100 "largely uncontacted" peoples which prefer to be left alone. There is some dispute over how appropriate the term "uncontacted" is because these peoples have generally been contacted at least once and are sometimes oppressed (Golub, 2008), but it appears to generally be agreed that at least many of these groups are isolated enough from the rest of the world that they are vulnerable to diseases to which people in most developed countries are resistant. Therefore, these societies may be relatively safe from diseases which are easier to transfer in a highly interconnected world, and they know how to survive without reliance on modern technology and infrastructure. Intuitively, it would be very challenging for a global catastrophe—at least the kind which could be mitigated by constructing refuges—to kill all of these people at once.

Section 4: Might refuges be essential for recovery from a global catastrophe?

Let's begin by getting a sense of the range of global catastrophes that have been proposed. Drawing from Bostrom (2002), Bostrom and Cirkovic (2008), Bostrom (2013), Hanson (2008), Jebari (2014), Posner (2004), and Rees (2003), I get the following list of proposed catastrophe scenarios: alien invasion, AI, asteroids and comets, climate change, cosmic rays, gamma-ray bursts, global ecophagy from nanotechnology ("grey goo"), nuclear war (including the special case of cobalt bombs[1]), conventional wars and terrorist attacks, pandemics (natural and manmade), physics disasters (such as the "strangelet" scenario), simulation shutdown, supernovae, and supervolcanoes.[2] Hanson (2008) includes earthquakes and hurricanes among the global catastrophes where refuges could play a role, but, as I argue below, these threats do not seem severe enough to belong on this list. These sources were singled out because they are notable general discussions of global catastrophic risk or because they advocate for refuges.

This analysis excludes negative long-term cultural changes—even ones with potential long-term consequences for civilization such as a decline in fertility that leads to voluntary extinction (Bainbridge, 2009) or the rise of a totalitarian regime (Caplan, 2008)—on the grounds that they aren't naturally described as catastrophes and that refuges would have limited use in reducing their potential downsides.

In a 2009 special issue of *Futures* on human extinction (Vol. 41, #10), some human extinction scenarios involving multiple catastrophic events were presented. For example:

- Tonn and MacGregor (2009) present a scenario involving the destruction of the world's oil reserves, an avian flu pandemic, and a supervolcanic eruption.

- Carpenter and Bishop (2009) present a scenario involving an engineered superpandemic followed by an asteroid collision.

The number of catastrophes fitting this format grows combinatorially with the number of proposed individual catastrophes, and the probability of compound catastrophes is very small if the catastrophes are

largely independent. This analysis considers only single-catastrophe scenarios, leaving it to others to consider the potential value of refuges for aiding with survival and recovery in compound catastrophe scenarios.

Focusing then on single-catastrophe scenarios, building a refuge is a bet that:

(i) a global catastrophe will occur,

(ii) people in the refuge will survive the initial catastrophe, and

(iii) survivors in the refuge will have advantages over others that allow them to help civilization recover from the catastrophe, when others outside the refuge could not (at least without help from people in the refuges).

If one of these conditions does not hold, there is no distinctively compelling case for creating the refuge. If they all hold, then there could be a very compelling case for building refuges. Without assessing whether these catastrophes are likely to occur, this section will consider for which of the proposed catastrophes listed above, were they to happen, people in refuges plausibly fit (ii) and (iii).

"Overkill" scenarios: people in the refuges wouldn't survive

Some of these disasters, such as alien invasion and runaway AI, involve very powerful hostile forces. Refuges would be of limited use in these cases because such forces would probably have little trouble destroying any survivors.

Some disasters would be so complete/destructive that people in refuges couldn't survive. These probably include global ecophagy from nanotechnology, physics disasters like the "strangelet" scenario, and simulation shutdowns.

"Underkill" scenarios: not enough damage for refuge to be relevant

If the catastrophe leaves enough people, resources, relevant skills, and coordination, then the refuge won't be necessary for recovery.

Pace Hanson (2008), earthquakes and hurricanes probably fit this description. The upper limit for the destructiveness of earthquakes appears to be not much higher than 9.6 on the Richter scale due to limits to how much pressure rocks can take before breaking (Saunders, 2011). An earthquake of this size happened in Chile in 1960 and was very far from being a global catastrophe. Hanson relies on the assumption that earthquakes follow a power law distribution, but physical factors dictate that this distribution needs to be truncated before global catastrophe becomes a realistic possibility. Similarly, it's likely that physical limits prevent hurricanes from creating global catastrophes.

Not many of the other catastrophes clearly fit this description. It's true that very few, if any, of them would be potentially survivable yet result in sudden extinction (more under "sole survivors of a period of intense destruction"). But it's conceivable that several could lead to extinction or failure to recover following the initial catastrophe. Many would survive the immediate effects of asteroids and comets, nuclear wars, and supervolcanoes, but it is more debatable how many would survive the global food crisis following them (more under "global food crisis scenarios"). Similarly, it's conceivable that destruction from the above scenarios, an unprecedentedly bad pandemic, or an unprecedentedly bad non-nuclear global war could lead to a collapse of the modern world order (more under "social collapse scenarios").

Very long-term environmental damage: refuges don't address the problem

Some proposed global catastrophic risks operate via permanent or very long-term negative consequences for the environment. These include climate change, gamma-ray bursts, and supernovae. This category could also include several of the overkill scenarios described above. Refuges would be of little help in these cases.

Sole survivors of a period of intense destruction: very little scope for this

Conceivably, people in some refuge could be the only ones with defenses adequate to withstand a period of intense destruction (an "intense destruction" scenario). If that happened, they could be critical for the

long-term survival of humanity. (Note: In this category, I mean to exclude global food crises and social collapse, and focus cases of ongoing active destruction (such as from conflict, hostile forces, disease, disasters, and so on.))

Refuge advocates have placed some of their hopes in this category. Hanson (2008), Matheny (2007), and Jebari (2014) all devote space to discussion of minimal viable population size and the importance of protection from fallout and other forms of destruction. Moreover, if refuges could be the sole survivors of some global catastrophic risk involving a period of intense destruction, it would make a very compelling case for their construction. However, with the possible exception of pandemic specifically engineered to kill all humans and the detonation of cobalt bomb made with similar intentions, I am aware of no proposed scenario in which a refuge would plausibly enable a small group of people to be the sole survivors of a period of intense destruction.

Going through the above scenarios:

- The overkill scenarios of alien invasions, runaway AI, global ecophagy from nanotechnology, physics disasters like the "strangelet" scenario, and simulation shutdowns, are excluded.
- The underkill scenarios of earthquakes and hurricanes are excluded.
- The global food crisis scenarios of asteroids, supervolcanoes, and nuclear winter are excluded. At least under present (and declining) stocks of nuclear weapons, the immediate consequences of nuclear war would not threaten extinction. According to a 1979 report by the US Office of Technology Assessment (p. 8), even in the case of an all-out nuclear war between the US and Russia, only 35-77% of the US population and 20-40% of the Russian population would die within the first 30 days of the attack.
- The cases involving very long-term environmental damage (climate change, gamma-ray bursts, supernovae) are excluded.

- In conventional (non-nuclear, non-biological) wars and terrorist attacks, it's hard to see how rapid extinction could follow. It's hard to imagine, e.g., two sides simultaneously wiping out all remaining humans or each other's food supply using conventional weapons. Absent purposeful global destruction of all human civilizations, it's also unclear how this would destroy the 100+ "largely uncontacted" peoples.

That leaves pandemics and cobalt bombs, which will get a longer discussion. While there is little published work on human extinction risk from pandemics, it seems that it would be extremely challenging for any pandemic—whether natural or manmade—to leave the people in a specially constructed refuge as the sole survivors. In his introductory book on pandemics, Doherty (2013, p. 197) argues:

> "No pandemic is likely to wipe out the human species. Even without the protection provided by modern science, we survived smallpox, TB, and the plagues of recorded history. Way back when human numbers were very small, infections may have been responsible for some of the genetic bottlenecks inferred from evolutionary analysis, but there is no formal proof of this."

Though some authors have vividly described worst-case scenarios for engineered pandemics (e.g. Rees, 2003; Posner 2004; and Myhrvold, 2014), it would take a special effort to infect people in highly isolated locations, especially the 100+ "largely uncontacted" peoples who prefer to be left alone. This is not to say it would be impossible. A madman intent on annihilating all human life could use cropduster-style delivery systems, flying over isolated peoples and infecting them. Or perhaps a pandemic could be engineered to be delivered through animal or environmental vectors that would reach all of these people.

It might be more plausible to argue that, though the people in specially constructed refuges would not be the sole survivors of our hypothetical pandemic, they may be the only survivors in a position to rebuild a technologically advanced civilization. It may be that the rise of technologically advanced societies required many contingent factors—including cultural factors—to come together. For example,

Mokyr (2006) argues that a certain set of cultural practices surrounding science and industry were essential for ever creating a technologically advanced civilization, and that if such developments had not occurred in Europe, they may have never occurred anywhere. If such a view were correct, it might be more likely that people in well-stocked refuges would eventually rebuild a technologically advanced civilization, in comparison with societies that have preferred not to be involved with people using advanced technology. However, even if people familiar with Western scientific culture do survive, on a view like Mokyr's, there would be no guarantee that they would eventually rebuild an advanced civilization. This may be the most plausible proposed case in which refuges would make humanity more likely to eventually fully recover from a period of intense destruction that would otherwise quickly lead to extinction.

Jebari (2014) raises cobalt bombs as a potential use case for refuges. The concept of a cobalt bomb was first publicly articulated by Leó Szilárd in 1950, and he argued that it could result in human extinction. In a nuclear explosion, the non-radioactive cobalt-59 casing of a bomb would absorb neutrons and become cobalt-60, which is radioactive and has a longer half-life (5.26 years) than fallout from standard nuclear weapons. The hypothetical use case would involve a large quantity of cobalt-60 being distributed widely enough to kill all humans. People in refuges might be the sole survivors because it would take an extremely long time (perhaps decades) for radiation levels to become survivable for humans. Conceivably, people in an underground refuge with an unusually long-lasting food supply could be the only survivors. As mentioned above, government and private shelters generally do not hold more than about a year of food supply.

However, the online Nuclear Weapon Archive claims that, at least according to the public record, no cobalt bomb has ever been built. One known experimental attempt by the British to create a bomb with an experimental radiochemical tracer ended in failure, and the experiment was not repeated. Early analysis of the problem by Arnold (1950) concluded that it was uncertain whether neutrons could be absorbed to make cobalt-60 as intended, and that it was unlikely that the radioactive material could be

distributed evenly enough to create total extinction. More recent, and currently unpublished, results by Anders Sandberg reached a similar conclusion. Therefore, the cobalt bomb scenario seems both highly unlikely to occur and implausible as a sole survivors case.

Alternatively, it might be argued that, though refuges would be extremely unlikely to help a small number of people to survive any proposed intense destruction scenario, they might help a small number of people to survive some wholly unforeseen intense destruction scenario. Jebari (2014), for example, suggests that building the kind of refuges he proposes would help prevent "stochastic and unforeseen" "black swan extinction events." It seems impossible to prove otherwise, but the above analysis makes this possibility seem unlikely. The above arguments suggest that refuges are unsuited to increasing the chances of recovery from any known intense destruction scenario, and the default assumption would be that this would carry over to any given unforeseen intense destruction scenario. Moreover, the reasons that refuges would not help in intense destruction scenarios seem to generalize. Putative "intense destruction" scenarios tend to involve overkill, underkill, or operate through channels like global food crises or social collapse. It's natural to think that this generalization would hold for unforeseen future catastrophes.

Global food crisis scenarios: a potential use case

A global catastrophe could disrupt global food production for two reasons. First, as noted a few times above, some global catastrophes—such as supervolcanic eruptions, nuclear wars, and asteroid collisions—might put enough dust in the atmosphere to interfere with photosynthesis and disrupt global food production. Second, an initial catastrophe could kill enough people and do enough damage to infrastructure to shut down global food production. Conceivably, stocking refuges with a very large food supply or method of making food—over and above what is necessary to survive the initial catastrophe—might help a small group to survive and recover if a global catastrophe disrupts global food production.

A first issue is that a global food crisis would not necessarily result in extinction. Extinction may even be extremely unlikely in such cases. The closest historical precedent to these crises was the supervolcanic Toba eruption that took places about 74,000 years ago. Many eruptions of this kind have taken place in the last tens of millions of years, but they did not extinguish our pre-human ancestors (Shulman 2012a). Humans may now be in many ways worse prepared for such a crisis, with a much larger percentage of the population without hunting and agricultural skills, but we have many advantages in terms of technology and coordination. The 100+ isolated peoples would be relatively similar to pre-human ancestors who survived supervolcanic eruptions in the past, though—as noted above—they may have a notable disadvantage in re-establishing an advanced industrial civilization.

Second, in any of the global food crisis scenarios noted above, there would be a substantial amount of remaining food reserves in the form of grain stockpiles, livestock, fisheries, foods stored at retailers and private homes, and wild land animals that could be hunted (Shulman, 2012b). Therefore, if a refuge helps humanity survive a global food crisis, the mechanism could not be conceived of as "adding enough to the global food stock to help with survival." More plausibly, there could be a scenario where there isn't enough food for everyone to survive the global food crisis, but there would be enough food for some people to survive if they got a disproportionate share of the food. However, conflict (e.g., as in McCarthy's post-apocalyptic novel *The Road*) and/or egalitarian pressures could prevent a distribution that would allow at least some of the population to survive the crisis. Conceivably, if the refuge were sufficiently secret, isolated, and well-stocked, it might be the only place where these pressures could be abated, making the people in refuges the sole survivors of the global food crisis. While conceivable and perhaps plausible, refuges' unique success in this kind of case is not automatic and perhaps unlikely. If some small, well-armed group seizes some grain elevators, refuses to share their bounty, and successfully defends what they've claimed, they could also survive the global food crisis. Alternatively, a single survivalist community might be isolated and well-defended enough to achieve the same purpose. This potential use case may deserve more detailed analysis.

Social collapse scenarios: increased coordination may help

As noted above, even if some initial catastrophe failed to kill everyone, it could lead to a collapse of the modern world order. This type of scenario might accompany a global food crisis, or could arise independently in cases of an unprecedentedly bad pandemic or global war that decimates the population. Conceivably, such a collapse to lead to extinction or a failure to recover industrial civilization.

In this kind of scenario, people in refuges are not the sole survivors of our hypothetical global catastrophe. Instead, it seems extremely likely that, some non-negligible fraction of civilization (greater than 1 in 10,000, say) would survive. But a greatly reduced global population would be unable to sustain many aspects of modern industry, manufacturing, trade, and agricultural production, and may be forced to retrace a substantial part of past technological development (see Hanson (2008) quotation below).

Most of the global threats consistent with the above scenario would leave most of humanity's material resources (housing, farms, streets, mines, grain elevators, supply centers, etc.) in place, though much of it may cease to effectively function (e.g. power plants, manufacturing sites, oil rigs, etc.). From the above list of doomsday scenarios, nuclear war or other wars seem like the only potentially-survivable catastrophes with any potential to destroy a majority of available material resources. And, as argued above, even a nuclear war would have a hard time destroying a majority of the world's population outright. Therefore, whatever resources are stockpiled in specially constructed refuges would be a small fraction of all available material resources following any realistic proposed civilization collapse scenario. How could refuges be crucial for recovery if they contain a very small fraction of the population, food, and material resources in the world?

Hanson (2008) suggests that people in refuges might have rare and especially useful skills and resources:

> "It is important to realize that a society rebuilding after a near-extinction crisis would have a vastly smaller scale than our current society; very different types and mixes of capital would

> be appropriate. Stocking a sanctuary full of the sorts of capital that we find valuable today could be even less useful than the inappropriate medicine, books, or computers often given by first world charities to the third world poor today. Machines would quickly fall into disrepair, and books would impart knowledge that had little practical application.
>
> Instead, one must accept that a very small human population would mostly have to retrace the growth path of our human ancestors; one hundred people cannot support an industrial society today, and perhaps not even a farming society. They might have to start with hunting and gathering, until they could reach a scale where simple farming was feasible. And only when their farming population was large and dense enough could they consider returning to industry.
>
> So it might make sense to stock a refuge with real hunter-gatherers and subsistence farmers, together with the tools they find useful."

Hanson's proposal assumes a "sole survivors" scenario, which I've argued is unrealistic for this kind of case. But perhaps a refuge full of people with hunter-gatherer and subsistence farmer skills could be essential to recovery even if these survivors were a small fraction of the total population. Perhaps they could train other people, or perhaps the rest of the population wouldn't survive long after the initial catastrophe.

There are a couple potential complications with Hanson's idea:

- First, if many people outside of refuges survive the initial catastrophe, it's likely that many hunter-gatherers and subsistence farmers among "largely uncontacted peoples" will survive in any case. However, social collapse could be combined with a global food crisis that hunter-gatherers and subsistence farmers without access to large food reserves may have

trouble surviving. Moreover, as noted above, less technologically advanced societies may be less likely to eventually rebuild a technologically advanced civilization.

- Second, even if a small fraction of the population survives the initial catastrophe, many farmers, hunters, survivalists, and people interested in "living off the grid" will be among the survivors. Therefore, the people surviving in special refuges would still be a small portion of all people with relevant skills.

Perhaps the special appeal of such refuges involves the combination of people with relevant skills, food stockpiles, and other resource stockpiles together in a single location. Though people in refuges would hold only a small share of aggregate population, food stockpiles, material resources, and skills, they may be the only well-coordinated group high on all dimensions. For example, if an unprecedentedly bad pandemic left a tiny fraction of the population alive, the scattered survivors might have trouble coordinating that people in a refuge wouldn't. This possibility is perhaps worth considering more deeply, and may deserve a stronger place in the analysis favored by refuge advocates.

Conclusion

Refuges may initially seem like a reliable method of ensuring that civilization will recover from a wide range of potential catastrophes. However, on closer inspection, many existing systems serve similar functions, and refuges would have limited impact for many potential catastrophes. Many proposed catastrophes render refuges of limited use simple reasons: for "overkill" catastrophes, people in refuges can't survive anyway (these include alien invasions, runaway AI, global ecophagy from nanotechnology, physics disasters like the "strangelet" scenario, and simulation shutdowns); "underkill" catastrophes probably aren't destructive enough for refuges to be relevant (these include earthquakes and hurricanes);

and refuges are largely irrelevant to long-term environmental damage scenarios (these include climate change, gamma-ray bursts, supernovae).

Refuge advocates have focused on scenarios where people in refuges are the sole survivors of some period of intense destruction. If people in refuges were likely to be the sole survivors in multiple scenarios of that type, then there would be a clear and compelling rationale for building them. However, there are only a couple proposed scenarios where people in refuges could plausibly be the sole survivors (cobalt bombs and engineered pandemics), and even in these cases it's very debatable whether it would be possible to swiftly kill everyone in a way that people in refuges would be the sole survivors.

In global food crises and social collapse scenarios, refuges would add comparatively little to total population, skills, food, and other resources. If they add value, it is probably by keeping part of the population isolated, or maintaining coordination among enough people with food, material resources, and the right skills. Even in these cases, survivalist communities, small groups who seize and hoard food stockpiles, farmers, hunters, and isolated peoples may serve many of the intended functions of refuges.

At this point, it seems very doubtful that people in refuges would be the sole survivors of a period of intense destruction, and somewhat doubtful that they would play a crucial role in recovering from a global food crisis or social collapse. Without laying out the case in detail, I would conjecture that efforts to mitigate specific risks through more conventional biosecurity and nuclear security channels; strategically adding to general skills, capital, and food needed for survival and reconstruction in a post-catastrophe setting (factors more emphasized by Maher and Baum (2013)); or testing proposals for rapidly scaling up global food production in the event of a global food crisis would have a more significant impact on preventing a catastrophe from which we never recover.

Acknowledgements

This research was financially supported by GiveWell. I am grateful to my colleagues at the Future of Humanity Institute and the Centre for Effective Altruism for feedback on this essay, especially Robin Hanson, Anders Sandberg, and Carl Shulman.

References

Arnold, J. 1950. The hydrogen-cobalt bomb. Bulletin of the Atomic Scientists, 6, 290-292.

Author. 2013. [Removed for blind review]

Bainbridge, W. S. 2009. Demographic collapse. Futures, 41(10), 738-745.

Ball, D. 2011.Swiss Renew Push for Bomb Shelters, The Wall Street Journal. URL:http://online.wsj.com/news/articles/SB10001424052702304231204576405700994655570. Accessed: 2014-01-17. (Archived by WebCite® at http://www.webcitation.org/6Mh0rJdZE)

Bostrom, N. 2002. Existential risks: Analyzing Human Extinction Scenarios and Related Hazards. Journal of Evolution and Technology. 9. URL: http://www.nickbostrom.com/existential/risks.html

Bostrom, N. 2003. Astronomical waste: The opportunity cost of delayed technological development. Utilitas. 15, 308-314.

Bostrom, N. 2013. Existential risk prevention as global priority. Global Policy. 4, 15-31.

Bostrom, N. and Cirkovic, M. (Eds.). 2008. Global Catastrophic Risks. Oxford University Press.

Caplan, B. 2009. The totalitarian threat, in Global Catastrophic Risks, edited by Nick Bostrom and Milan Cirkovic, Oxford Univeristy Press. URL:http://econfaculty.gmu.edu/bcaplan/total4.doc.

Carpenter, P. A., and Bishop, P. C. 2009. The seventh mass extinction: Human-caused events contribute to a fatal consequence. Futures, 41(10), 715-722.

Doherty, P. C. 2013. Pandemics: What Everyone Needs to Know. Oxford University Press.

Freitas, R. 2000. Some Limits to Global Ecophagy by Biovorous Nanoreplicators, with Public Policy Recommendations, Foresight Institute Technical Report. URL:http://www.foresight.org/nano/Ecophagy.html. Accessed: 2014-01-23. (Archived by WebCite® at http://www.webcitation.org/6MqC07C6Y)

GlobalSecurity.org, Mount Weather. URL:http://www.globalsecurity.org/wmd/facility/mt_weather.htm. Accessed: 2014-01-23. (Unable to archive on WebCite®.)

Golub, A. 2008. Are there 'uncontacted tribes'? The short answer: No. Savage Minds: Notes and Queries in Anthropology (blog). URL:http://savageminds.org/2008/07/01/are-there-uncontacted-tribes-the-short-answer-no/. Accessed: 2014-08-22. (Archived by WebCite® at http://www.webcitation.org/6S14p0OsO)

Hanson, R. 2008. Catastrophe, social collapse, and human extinction, in Global Catastrophic Risks, edited by Nick Bostrom and Milan Cirkovic, Oxford Univeristy Press. URL:http://hanson.gmu.edu/collapse.pdf.

Jebari, K. 2014. Existential Risks: Exploring a Robust Risk Reduction Strategy. Science and Engineering Ethics, 1-14.

Kearny, Cresson H. 1986. Nuclear War Survival Skills. Oak Ridge, TN: Oak Ridge National Laboratory.

Kosseff, J. 2007. DeFazio asks, but he's denied access, The Oregonian. URL: http://web.archive.org/web/20070810100224/http://www.oregonlive.com/news/oregonian/index.ssf?/base/news/118489654058910.xml&coll=7

Maher, T. M., & Baum, S. D. 2013. Adaptation to and recovery from global catastrophe. Sustainability, 5, 1461-1479.

Matheny, J. 2007. Reducing the Risk of Human Extinction, Risk Analysis 27:1335-44. URL: http://users.physics.harvard.edu/~wilson/pmpmta/Mahoney_extinction.pdf.

McCarthy, Cormac. 2009. The Road. Pan Macmillan.

Mokyr, J. 2006. King Kong and cold fusion: Counterfactual analysis and the history of technology, in: Tetlock, P. E., Lebow, R. N., & Parker, G. (Eds.).Unmaking the West: What-if Scenarios that Rewrite World History. University of Michigan Press.

Muehlhauser, L., and Salamon, A. 2012. Intelligence Explosion: Evidence and Import. In Singularity Hypotheses: A Scientific and Philosophical Assessment, edited by Amnon Eden, Johnny Søraker, James H. Moor, and Eric Steinhart. Berlin: Springer. URL:http://intelligence.org/files/IE-EI.pdf.

Myhrvold, N. 2013. Strategic Terrorism: A Call to Action, in the Lawfare research paper series.

Navy Times. Mabus: First women selected for attack subs. URL:http://www.navytimes.com/article/20130124/CAREERS/301240311/Mabus-First-women-selected-for-attack-subs. Accessed: 2014-01-22. (Archived by WebCite® at http://www.webcitation.org/6Motkeqtn)

O'Connor, C. Selling The Apocalypse: Would You Pay $50,000 To Be 'Saved'? Forbes. URL:http://www.forbes.com/sites/clareoconnor/2011/04/21/selling-the-apocalypse-would-you-pay-50000-to-be-saved/. Accessed: 2014-01-21. (Archived by WebCite® at http://www.webcitation.org/6MnJiJIrZ).

Parfit, D. 1984. Reasons and Persons. Oxford University Press.

Patrol Log. 2010. Are Doomsday Shelters Coming Back in Style? Web resource. URL:http://www.patrol-log.com/2010/07/28/are-doomsday-shelters-coming-back-in-style/. Accessed: 2014-01-17. (Archived by WebCite® at http://www.webcitation.org/6MhBnR32A)

PBS. Tour the Greenbrier Bunker. Web resource. URL:http://www.pbs.org/wgbh/amex/bomb/sfeature/bunker.html. Accessed: 2014-01-17. (Archived by WebCite® at http://www.webcitation.org/6Mh9scb3C)

Pegg, D. 2011. The 25 Most Remote Places In The World. Web resource. URL:http://list25.com/the-25-most-remote-places-in-the-world/?view=all. Accessed: 2014-01-24. (Archived by WebCite® at http://www.webcitation.org/6MrndqJWM)

Posner, R. 2004. Catastrophe: Risk and Response.

Radius Engineering, About Radius. URL:http://undergroundshelters.com/news/. Accessed: 2014-01-21. (Archived by WebCite® at http://www.webcitation.org/6MnKGjwTO)

Radius Engineering, Key Features. URL:http://undergroundshelters.com/key_features/. Accessed: 2014-01-21. (Archived by WebCite® at http://www.webcitation.org/6MnK1cGFL)

Rees, M. 2003. Our Final Century. Heinemann.

Sandberg, A. Unpublished manuscript. Nuclear holocaust.

Saunders, C. 2011. How big can an earthquake be? Sci/Why (blog). URL:http://sci-why.blogspot.co.uk/2011/06/how-big-can-earthquake-be.html. Accessed: 2014-08-22. (Archived by WebCite® at http://www.webcitation.org/6S1SFbpu8)

Shulman, C. 2012a. What to eat during impact winter? Reflective Disequilibrium (blog). URL:http://reflectivedisequilibrium.blogspot.co.uk/2012/05/what-to-eat-during-impact-winter.html. Accessed: 2014-01-24. (Archived by WebCite® at http://www.webcitation.org/6MrmVY18N)

Shulman, C. 2012b. Nuclear winter and human extinction: Q&A with Luke Oman. URL:http://www.overcomingbias.com/2012/11/nuclear-winter-and-human-extinction-qa-with-

luke-oman.html. Accessed: 2014-08-29. (Archived by WebCite® at http://www.webcitation.org/6SBfV1k0T)

Stender, J.M. Ready, Prep, Go. URL: http://finmagazine.sjmc.umn.edu/index-p=937.html. Fin. Accessed: 2014-01-17. (Archived by WebCite® at http://www.webcitation.org/6MhDlZNNd)

Subette, C. The Nuclear Weapon Archive: A Guide to Nuclear Weapons. Web resource. URL:http://nuclearweaponarchive.org/. Accessed: 2014-08-27. (Archived by WebCite® at http://www.webcitation.org/6S8yEFruW)

Survival International, BBC: First contact with isolated tribes? URL:http://www.survivalinternational.org/news/2191. Accessed: 2014-01-22. (Archived by WebCite® at http://www.webcitation.org/6MovVDnnv)

Tonn, B., and MacGregor, D. 2009. A singular chain of events. Futures, 41(10), 706-714.

US Navy. Submarine frequently asked questions. Web resource. URL:http://www.navy.mil/navydata/cno/n87/faq.html. Accessed: 2014-01-22. (Archived by WebCite® at http://www.webcitation.org/6MotGMQPF)

US Navy. The Submarine. Web resource. URL:http://www.navy.mil/navydata/ships/subs/subs.asp. Accessed: 2014-08-29. (Archived by WebCite® at http://www.webcitation.org/6SBsBmUlZ)

US Office of Technology Assessment. 1979. The Effects of Nuclear War.

Vivos. Prepare. Web resource. URL:http://www.terravivos.com/secure/prepare.htm. Accessed: 2014-01-23. (Archived by WebCite® at http://www.webcitation.org/6MqEwNeQt)

Vivos. Strategically Located in Central Indiana. Web resource. Accessed: 2014-01-17. URL: http://www.terravivos.com/secure/indiana.htm. (Archived by WebCite® at http://www.webcitation.org/6MhEDr6rc)

Vivos. World's Only Doomsday Human Seed Vault. Web resource. URL: http://www.terravivos.com/secure/cryo1.htm. Accessed: 2014-01-17. (Archived by WebCite® at http://www.webcitation.org/6MhE0voaA)

[1] The concept of a cobalt bomb was first publicly articulated by Leó Szilárd in 1950, and he argued that it could result in human extinction. In a nuclear explosion, the non-radioactive cobalt-59 casing of a bomb would absorb neutrons and become cobalt-60, which is radioactive and has a longer half-life (5.26 years) than fallout from standard nuclear weapons. The hypothetical use case would involve a large quantity of cobalt-60 being distributed widely enough to kill all humans.

[2] Supervolcanoes, comets and asteroids, supernovae, gamma-ray bursts, cosmic rays, pandemics, AI, physics disasters, nuclear war, and global ecophagy from nanotechnology are discussed in the Table of Contents of Bostrom and Cirkovic (2008), see the Table of Contents, Pgs xvi-xxii. Simulation shutdown and alien invasion are discussed in Bostrom 2002. Wars, earthquakes, and hurricanes are discussed by Hanson (2008, p.367-369). Jebari (2014) discusses cobalt bombs.